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NASA Advanced Space Photovoltaic Technology—Status, Potential and Future Mission Applications

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NASA ADVANCED SPACE PHOTOVOLTAIC TECHNOLOGY -

STATUS, POTENTIAL AND FUTURE MISSION APPLICATIONS

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SUMMARY

The NASA program in space photovoltaic research and development encompasses a wide range of emerging options for future space power systems, and includes both cell and array technology development. The long range goals are to develop technology capable of achieving 300 W/kg for planar arrays, and 300 W/m^2 for concentrator arrays. InP and GaAs planar and concentrator cell technologies are under investigation for their potential high efficiency and good radiation resistance. The Advanced Photovoltaic Solar Array (APSA) program is a near term effort aimed at demonstrating 130 W/kg beginning of life specific power using thin (62 μm) silicon cells. It is intended to be technology transparent to future high efficiency cells and provides the baseline for development of the 300 W/Kg array.

INTRODUCTION

NASA, through its Office of Propulsion and Power, conducts a continuing space energy conversion research and technology program of wide ranging scope and content. The primary objective of the program is to provide a broad technology base to meet power system requirements for future space missions, including growth space station, advanced Earth orbiting satellites, lunar and planetary bases, and solar system exploration. Power system requirements for those future missions will span the range from a few kilowatts to megawatts, and operating lifetimes will vary from 2 years to perhaps multiple decades. In some mission scenarios, such as a lunar or Mars base, a new planning element will be introduced: the mission capabilities will evolve over time from the initial outpost with intermittent operation to a permanent base with continuous operation. The impact on power system requirements and capabilities is just beginning to be assessed, but it is clear that an evolutionary technology development strategy will be needed to address this most ambitious of all manned space mission scenarios. As in any program of limited resources, it is essential to address those technologies that represent mission critical capabilities, and which have the broadest application across the entire mission set.

The photovoltaic element of the space energy conversion program is designed to provide the technology for improved conversion efficiency, reduced mass, reduced cost, and increased operating life of solar cell cells and arrays. At present, the program is divided into a generic base R&T effort, and a more focused effort for lunar or Mars surface power systems under Project Pathfinder. This paper will discuss some of the key technologies under develepement in the base R&T program and how they are expected to benefit future Agency missions. The program is divided roughly into two elements (that have synergistic overlap), each of which is managed by a separate research center. The Lewis Research Center is responsible primarily for research and development of advanced space solar cells and for investigating issues relating to advanced blanket technology. The Jet Propulsion Laboratory is primarily concerned with the development of high performance array technology, and for maintaining engineering data on the radiation damage resistance of cells that are available from commercial suppliers. The two centers also maintain facilities for direct cell calibration at high altitude, and both provide secondary standard measurements for flight programs and for assessing the progress of industrial and university laboratory advanced cell development efforts.

A specific long range goal of the base R&T program is to develop the technology base for photovoltaic arrays with a specific power of 300 W/kg at beginning of life (BOL). Achievement of this technology goal will improve the payload fraction of future earth orbiting spacecraft, and extend the potentially useful range of photovoltaic power systems on interplanetary spacecraft. The increased sophistication and long lead time of future missions, along with anticipated launch vehicle constraints, will place a premium on system reliability, lifetime and mass. For many current spacecraft almost half of the total spacecraft mass is taken up by the auxiliary propulsion and power subsystems, while the payload accounts for about one-fourth of the total. Reducing the mass of the nonpayload portion of the spacecraft by one-third would permit a doubling of the mass allocation for the payload. The extra mass allocation could be used for the addition of equipment to enhance operations, autonomy, reliability, redundancy and lifetime of the payload.

The overall thrust of the NASA space energy conversion research and technology program is aimed at achieving these mass and reliability benefits. For example, current solar arrays have specific powers in the range from 15 to 30 W/kg. NASA-sponsored technology has already shown that 66 W/kg is achievable, and the program is now aimed toward a proposed demonstration of 130 W/kg, using the NASA-developed 62 μm thick high efficiency silicon solar cell. The preceeding work is described in the section on high performance arrays. Achievement of the goal mentioned at the outset, i.e., 300 W/kg, especially when coupled with improved radiation resistance, will require not only improvements in array structures and blankets, but new, ultrahigh specific power solar cells as well. Some of the work on advanced cell technology is described in the next section of the paper. The successful realization of all the required technology elements will provide spacecraft designers with a ten-fold increase in solar array specific power compared to present practice, and open up new mission opportunities previously thought inaccessible to photovoltaic power systems.

ADVANCED SOLAR CELL TECHNOLOGY

The research on high performance solar cells conducted by NASA Lewis is focused on radiation tolerance and high efficiency, with special emphasis on indium phosphide (InP) and gallium arsenide (GaAs) devices. The InP work has three major thrusts: (1) demonstrating a cell structure capable of achieving 20 percent AMO efficiency with 1 percent or less degradation in power after 10 years in GEO; (2) heteroepitaxial growth of InP on alternate substrates such as silicon or germanium; and (3) demonstration of high efficiency, ultrathin InP cells with improved radiation resistance compared to GaAs and silicon. The papers by Weinberg, et al. (ref. 1) and by Brinker, et al. (ref. 2) in this volume provide an excellent update on some recent results and the potential of this exciting new cell technology. Other details appear in the paragraphs below. Work on GaAs cells similarly has three major thrusts: (1) development of high efficiency concentrator cells; (2) demonstrating feasibility of the point contact junction geometry in GaAs; and (3) development of a V-grooved cell geometry with improved efficiency and radiation resistance compared to the standard cell geometry. The paper by Bailey, et al. (ref. 3) describes the latter in more detail.

In addition to the areas mentioned above, the Agency has a growing interest in the so-called thin-film cell technologies such as amorphous silicon and copper indium diselenide. There are two primary reasons for such interest: (1) the potential radiation resistance of these ultra-thin devices, and (2) the possibility of their extremely low cost. Internal Agency assessments indicate that these cell types will only be of value if they can be incorporated on very lightweight, flexible solar array blankets (such as Kapton) that can be easily deployed or erected, and which have a large volumetric power density when stowed on a spacecraft during launch and transport. Some of the basic stability issues associated with these cell types are being addressed in the Surface Power program, which has been discussed elsewhere (ref. 4).

Work on InP solar cells has resulted in an achieved efficiency of 18.8 percent in laboratory devices (ref. 5) in an n/p homojunction structure. A second cell type, produced by sputtering ITO onto InP (ref. 6), has produced efficiencies in excess of 16 percent and with a level of radiation resistance equivalent to that observed in the OMCVD-produced homojunction device (ref. 7). Efforts to fabricate InP cells on alternate substrates have been directed entirely toward silicon thus far. Progress to date has been encouraging, and despite the large lattice mismatch that exists between silicon and InP, it is felt that epitaxial growth can be accomplished with sufficiently high epitaxial layer quality that efficiencies above 19 percent can be realized. The first devices were produced with unoptimized growth conditions and structures, and had efficiencies above 9 percent (ref. 8). The intent is to incorporate the optimized high efficiency structure that will be developed in thrust one on an alternate substrate to improve ruggedness and reduce cost. Work in the third area, the ultrathin InP cell, has just begun, and will utilize the CLEFT process developed by John Fan and co-workers to produce high specific power GaAs cells (ref. 9). Once achieved, the CLEFT device will be mechanically bonded to a low cost, rugged, lightweight substrate and tested for its spaceflight worthiness. Both planar and concentrator cell structures will be investigated in all of the above work.

Significant progress on GaAs concentrator cells has been achieved recently, both in understanding its radiation resistance, and in improving its performance. Employing a prism cover on the cell allows for a much simpler and more effective parallel gridline pattern to be used and still maintain good current collection. The equilibrium operating temperature of a concentrator array on orbit is expected to be 100 °C. Prism covered cells operating at 100 suns and 100 °C have exceeded 22 percent efficiency in laboratory measurements at NASA Lewis. The radiation resistance of the concentrator cell structure is not fully characterized, but early results suggests that it is not much different from that observed in p/n planar cells. Although the reflective concentrator optics that have been developed by NASA and the Air Force should provide significant shielding from the natural radiation background, they also restrict the specific power of such arrays to 30 W/kg or less. Use of a lightweight refractive concentrator such as the domed mini-Fresnel lens under developement by NASA and the SDIO can raise the specific power by a factor of two or three, but will require the cell to be significantly more radiation resistant than in the former case.

The fundamental requirements that must be met to demonstrate a high efficiency point contact GaAs cell are reasonably well understood (ref. 10). The structure should have a p-type, high resistivity base with fully passivated front and back surfaces, and the total junction areas should be on the order of 1 percent of the cell area. If the cell is to have good radiation resistance, the base diffusion length should be on the order of 100 µm, and the surface passivation should be unaffected by bombardment of charged particle radiation. Putting the junction areas on the back of the cell, as in the silicon point contact cell (ref. 11), implies that ultrathin cells with light trapping may be required for maximum efficiency. No experimental data are available at present.

Development of a high efficiency, lightweight, rugged, radiation resistant solar cell is an essential element of the NASA program to demonstrate the technology needed to achieve an array specific power of 300 W/kg for a deployable planar array. The Agency also has the goal to demonstrate technology for achieving 300 W/m^2 at specific powers approaching 100 W/kg in concentrator arrays. Excellent progress toward both sets of goals continues to be made.

HIGH PERFORMANCE SOLAR ARRAYS

The key element in the present JPL high performance array development work is the thin (62 µm) silicon solar cell. The presently available device represents the results of many years development, from initial device research, to pilot line operation, and finally to circuit assembly and test. The lightweight cell, in combination with a thin protective cover, allows the assembly of very low mass circuits and blankets. The reduction of the blanket mass then allows the mass of the support structure to be significantly reduced, yet still provide sufficient stiffness and strength.

In 1985, the program emphasis on the development of advanced array components was reduced in order to initiate the design and fabrication of a prototype wing that would demonstrate the integration of various array elements, such as thin cells and covers, and lightweight substrates and deployment systems. That effort, APSA (Advanced Photovoltaic Solar Array), is presently in hardware fabrication phase and is expected to demonstrate the capability for achieving greater than 130 W/kG for a 5 kWe (BOL) deployable wing (ref. 12). The wing design is scalable over a range of approximately 2 to 13 kW by changing width and length. Since certain elements such as the blanket housing and deployment motor do not change linearly with array power, the specific performance will range from approximately 90 to 150 W/kg from smallest to largest power levels. These high specific power values were achieved by commitment to low array mass and avoiding the tendency to increase mass by the addition of features that were not absolutely necessary. For example retraction is not a feature of the APSA design. JPL and TRW surveys of potential users indicated that although many endorsed array retraction and restowage, few could actually cite a mission or requirement that would actually require retraction. Consequently the present APSA design will not retract and relatch without manual assistance. At the same time the design can be modified at a modest mass penalty to provide automated retraction and relatching, if required.

Although APSA is based on the use of thin silicon cells, it is felt that more advanced cell types can be readily used when available. Initial prospects include thin GaAs and InP based devices, most likely on a rugged substrate. Due to the high density of the III-V materials, it is necessary that their thickness be on the order of a few mils for that array specific performance to complete with values obtained with thin silicon. However, the higher available cell efficiencies will allow for a reduction in required array area, a feature which can be important in some applications. In contrast, a number of thin film materials such as $CuInSe_2$ and amorphous silicon, due to their extreme thinness, offer the potential for very high specific performance, even at low overall efficiency (9-10 percent). Typically, a large increase in array area will be required when compared to the single crystal devices. However, if encouraging preliminary results on radiation resistance can be maintained for higher efficiency spaceworthy configurations, thin film array areas for severe radiation environments may be comparably small. At this point in time these thin film materials present many difficulties before being capable of space applications. These include problems of uniformity, stability, and the lack of availability in the form of a large area flexible film blanket.

As the development of the APSA prototype nears completion, the advanced array development program will then address ground based testing, and ultimately a space based test of the electrical and dynamic characteristics. At the same time emphasis will again be placed on array component technology development including evaluation of environmental, electrical and mechanical properties of the next generation of solar cells. Structure development will address questions of increased strength for enhanced spacecraft maneuverability and for lunar and planetary applications. The impact of a truly "flexible" cell blanket configuration will be examined to ascertain alternative stowage, deployment, and structural concepts. Array design for power levels beyond the APSA limits will be examined for potential SEP missions. The long term goal at this time still is to achieve extremely high specific performance (300 W/kg) for a wide range of mission applications.

CONCLUSIONS

The major requirements for space photovoltaic solar arrays and cells are high efficiency, low mass and survivability in the naturally occurring charged particle space radiation environment. The NASA space photovoltaic program is directed at providing the technology base for achieving such performance, and will provide a variety cell and array options for future mission planners to consider.

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16. Abstract

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